US009470138B2

(12) United States Patent
Miyagawa

(10) Patent No.: US 9,470,138 B2
(45) Date of Patent: Oct. 18, 2016

(54) **COOLANT CIRCULATION SYSTEM FOR ENGINE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 228 days.

(21) Appl. No.: **13/721,961**

(22) Filed: **Dec. 20, 2012**

(65) **Prior Publication Data**

US 2013/0160723 A1 Jun. 27, 2013

(30) **Foreign Application Priority Data**

Dec. 22, 2011 (JP) 2011-281643

(51) **Int. Cl.**
F01P 7/16 (2006.01)
F01P 3/02 (2006.01)

(52) **U.S. Cl.**
CPC ***F01P 7/16*** (2013.01); ***F01P 7/167*** (2013.01); *F01P 2003/027* (2013.01); *F01P 2060/04* (2013.01); *F01P 2060/08* (2013.01); *F01P 2060/16* (2013.01)

(58) **Field of Classification Search**
CPC F01P 7/14; F01P 2007/146; F01P 7/16; F01P 7/165; F01P 7/167
See application file for complete search history.

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(57) **ABSTRACT**

A coolant circulation system for an engine includes a cylinder block passage and a cylinder head passage, which are provided respectively in a cylinder block portion and a cylinder head portion of the engine. These two passages serve as passages through which a coolant flows to cool the cylinder block portion and the cylinder head portion. The cylinder block passage and the cylinder head passage are connected in parallel to each other. The coolant circulation system further includes a first heat exchanger connected to the cylinder block passage, a second heat exchanger connected to the cylinder head passage, a radiator connected to both the cylinder block passage and the cylinder head passage, and a control unit capable of controlling flow rates of the coolant flowing through the cylinder block passage and the cylinder head passage respectively.

17 Claims, 3 Drawing Sheets

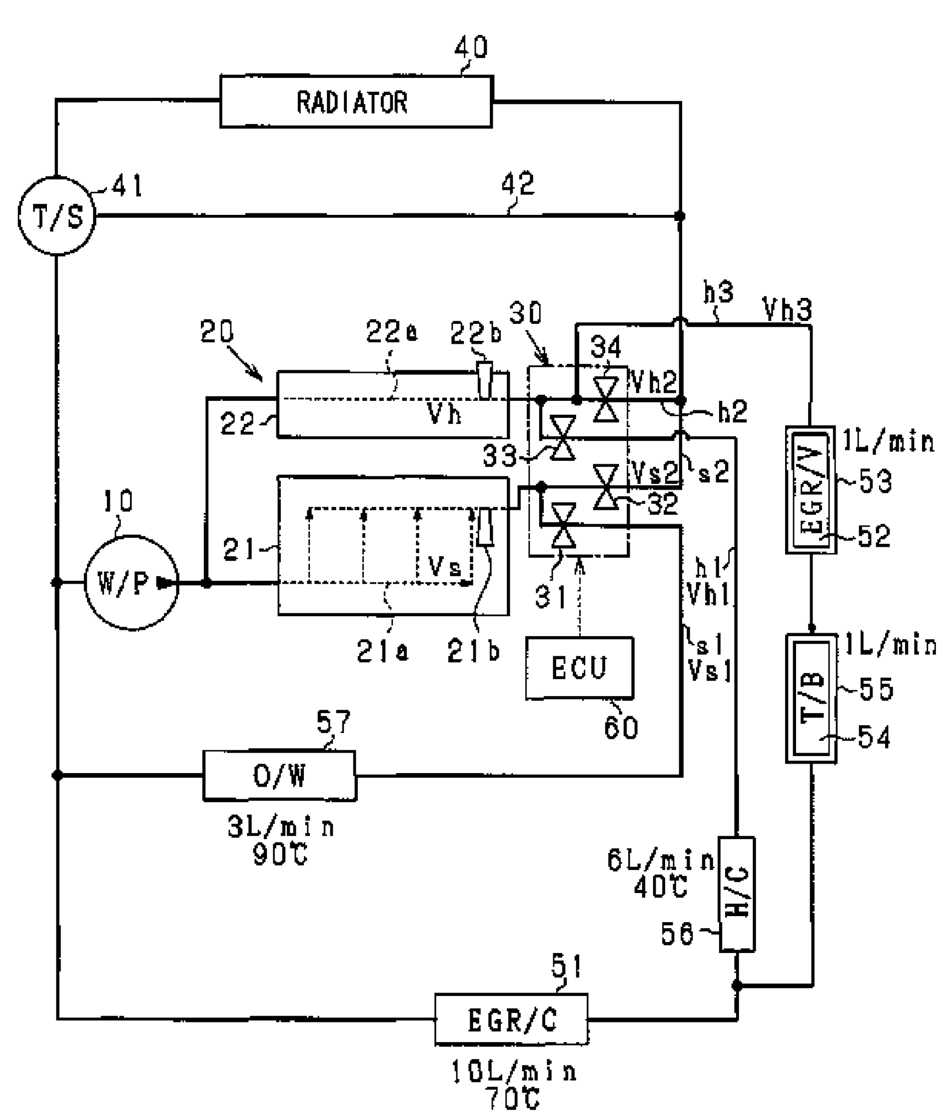


FIG. 1

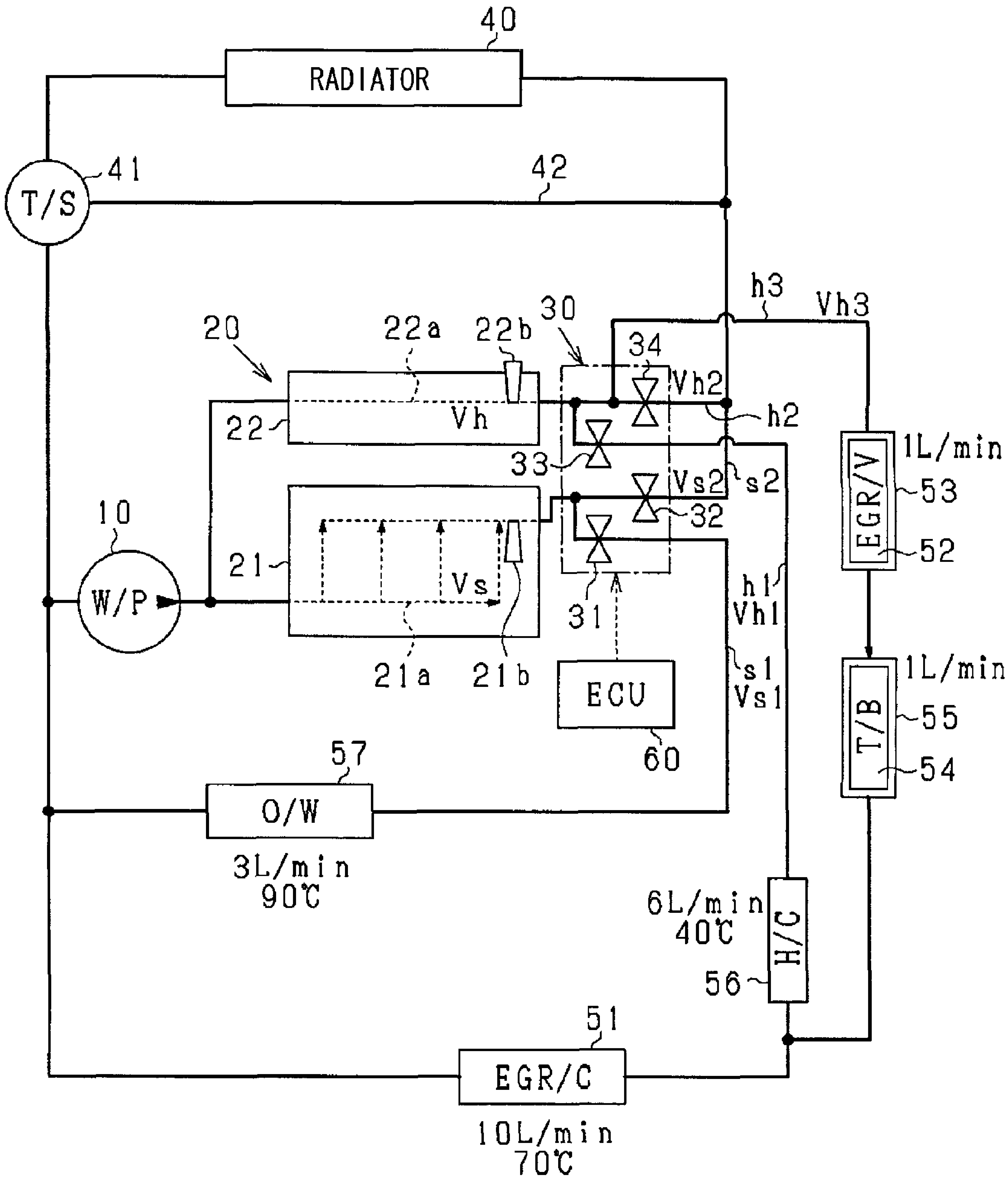
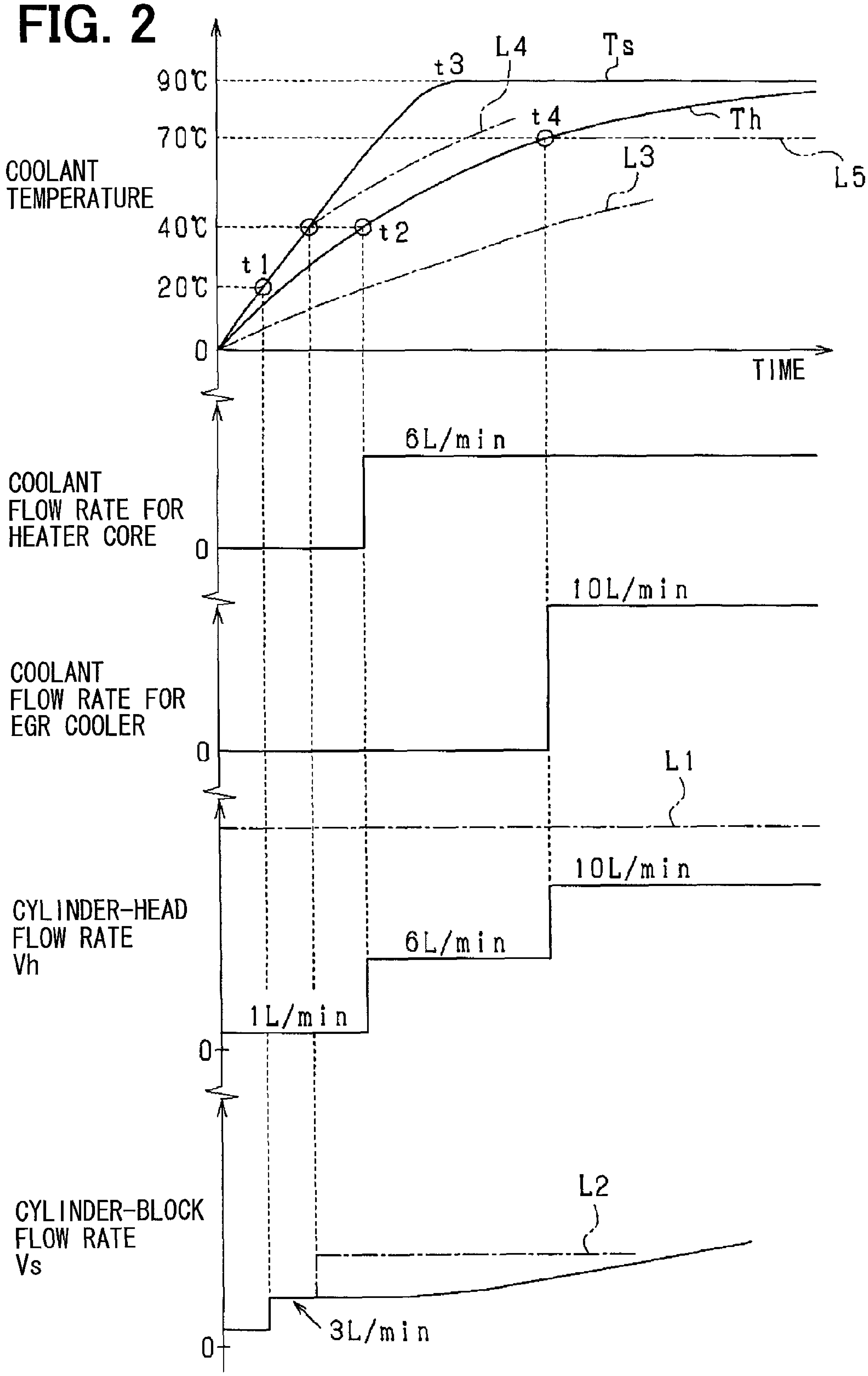
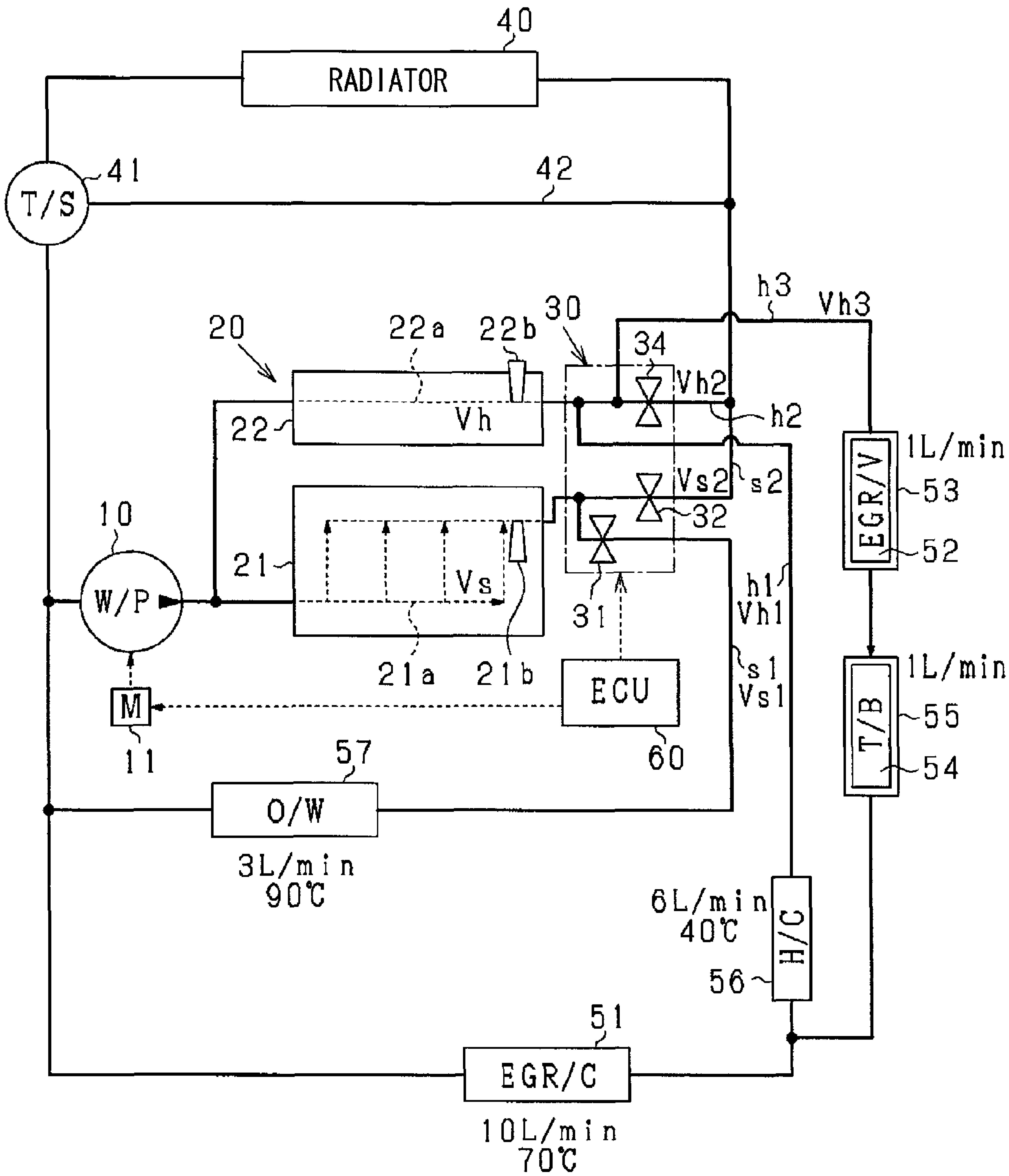

40
RADIATOR
41
T/S
42
h3
Vh3
20
22a
22b
30
34
Vh2
h2
22
Vh
33
Vs2
s2
1L/min
EGR/V
53
52
10
W/P
21
Vs
32
31
h1
Vh1
21a
21b
ECU
60
s1
Vs1
1L/min
T/B
55
54
57
O/W
3L/min
90℃
6L/min
40℃
H/C
56
51
EGR/C
10L/min
70℃

FIG. 2



COOLANT TEMPERATURE
90℃
70℃
40℃
20℃
0
t1
t2
t3
t4
L4
Ts
Th
L3
L5
TIME
COOLANT FLOW RATE FOR HEATER CORE
0
6L/min
COOLANT FLOW RATE FOR EGR COOLER
0
10L/min
L1
CYLINDER-HEAD FLOW RATE Vh
10L/min
6L/min
1L/min
0
CYLINDER-BLOCK FLOW RATE Vs
L2
3L/min
0

FIG. 3



40
RADIATOR
T/S
41
42
h3
Vh3
20
22a
22b
30
34
Vh2
h2
22
Vh
1L/min
EGR/V
53
Vs2
s2
32
52
10
W/P
21
Vs
h1
Vh1
31
21a
21b
ECU
s1
Vs1
1L/min
T/B
55
54
M
11
60
57
O/W
3L/min
90℃
6L/min
40℃
H/C
56
51
EGR/C
10L/min
70℃

COOLANT CIRCULATION SYSTEM FOR ENGINE

CROSS REFERENCE TO RELATED APPLICATION

This application is based on and incorporates herein by reference Japanese Patent Application No. 2011-281643 filed on Dec. 22, 2011.

TECHNICAL FIELD

The present disclosure relates to a coolant circulation system in which a coolant flows through a cylinder block portion and a cylinder head portion of an engine to cool the engine.

BACKGROUND

When an engine is warmed up, it is preferable that a temperature of lubricant oil for the engine is increased quickly so as to reduce a friction loss between a cylinder block portion and pistons of the engine, for example. In this case, a temperature (cylinder block temperature) of the cylinder block portion may be increased in preference to increasing a temperature (cylinder head temperature) of a cylinder head portion of the engine having a combustion chamber. Accordingly, the friction loss can be reduced effectively.

In a circulation system described in Patent Document 1 (JP 6-193443 A), a cylinder block portion of an engine has a cylinder block passage through which a coolant flows, and a cylinder head portion of the engine has a cylinder head passage though which the coolant flows. The cylinder block passage and the cylinder head passage are connected in parallel. In a warm-up operation of the engine, a coolant temperature (cylinder block temperature) in the cylinder block portion is increased more rapidly than a coolant temperature (cylinder head temperature) in the cylinder head portion is, by reducing an open degree of a control valve that controls a flow rate (cylinder-block flow rate) of the coolant flowing thorough the cylinder block portion.

Recently, an engine is equipped with an exhaust gas recirculation system (EGR system) in which a part of exhaust gas adapted as EGR gas flows back to an intake side of the engine, and the EGR gas is cooled by an EGR cooler. The EGR cooler, i.e., a heat exchanger is provided in an EGR pipe that connects an intake pipe and an exhaust pipe, and the EGR cooler exchanges heat between the EGR gas and a coolant. Here, a coolant used for the engine is generally distributed to the EGR cooler, and in this case, it is preferable that the coolant is distributed to the EGR cooler at a flow rate optimized for heat exchange in the EGR cooler.

In addition to the EGR cooler, there are various heat exchangers and portions to which coolant is required to be distributed. The various heat exchangers and portions include a coolant passage (heat exchanger) provided in an EGR valve that controls a flow rate of the EGR gas, a coolant passage (heat exchanger) provided in a throttle valve that adjusts an intake air amount, an oil warmer (heat exchanger) that heats lubricant oil, and a heater core (heat exchanger) that heats conditioned air. When the coolant is distributed to these heat exchangers, a coolant flow rate distributed to each of the heat exchangers is preferably adjusted at a coolant flow rate desired for heat exchange performed in each of them.

However, the above-described conventional circulation system does not have a device that controls a coolant flow rate (cylinder-head flow rate) in the cylinder head passage. Thus, the cylinder-head flow rate is increased in accordance with decrease of the open degree of the control valve that controls the cylinder-block flow rate. Therefore, the cylinder-block flow rate is adjustable independently, but the cylinder-head flow rate may be unadjustable independently. When the coolant is distributed to the above-described various heat exchangers from the cylinder head passage in the conventional circulation system, the coolant may not be distributed to the heat exchangers at the desired flow rates.

Also when the coolant is distributed to the various heat exchangers from the cylinder block passage, the coolant may not be distributed to the heat exchangers at the desired flow rates in a case where the cylinder-block flow rate is reduced during the engine warm-up operation.

SUMMARY

An objective of the present disclosure is to provide a coolant circulation system for an engine, which distributes coolant to heat exchangers at flow rates respectively required in the heat exchangers while warm-up of the engine is accelerated.

According to an aspect of the present disclosure, a coolant circulation system is used for an engine that includes a cylinder block portion and a cylinder head portion. The coolant circulation portion includes a cylinder block passage, a cylinder head passage, a first heat exchanger, a second heat exchanger, a radiator and a control unit. The cylinder block passage is provided in the cylinder block portion to serve as a passage through which a coolant flows to cool the cylinder block portion, and the cylinder head passage is provided in the cylinder head portion to serve as a passage through which the coolant flows to cool the cylinder head portion. The cylinder block passage and the cylinder head passage are connected in parallel to each other. The first heat exchanger is connected to an outlet of the cylinder block passage, and the second heat exchanger is connected to an outlet of the cylinder head passage. The radiator is connected to both the outlet of the cylinder block passage and the outlet of the cylinder head passage. The control unit is configured to be capable of controlling a flow rate of the coolant flowing through the cylinder block passage and a flow rate of the coolant flowing through the cylinder head passage respectively.

Accordingly, the flow rate (cylinder-head flow rate) of the cylinder head passage and the flow rate (cylinder-block flow rate) of the cylinder block passage can be controlled respectively. Thus, the cylinder-head flow rate can be increased while the cylinder-block flow rate is reduced to promote warm-up of the engine. As a result, the coolant can be distributed to the first and second heat exchangers at desired flow rates, and the warm-up operation can be promoted.

A heat exchanger, in which a desired flow rate of the coolant for heat exchange therein is approximately same as the cylinder-head flow rate in the warm-up operation of the engine, may be used as the second heat exchanger. In this case, the coolant can be distributed to the second heat exchanger at a desired flow rate of the second heat exchanger, and the warm-up operation can be accelerated.

The first heat exchanger may be a heat exchanger in which a desired flow rate of the coolant for heat exchange therein is lower than a predetermined value. The second heat

exchanger may be a heat exchanger in which a desired flow rate of the coolant for heat exchange therein is higher than the predetermined value.

In the warm-up operation, it is effective for reducing a friction loss between the cylinder block portion and pistons that a temperature (cylinder block temperature) of the cylinder block portion is increased in preference to increase of a temperature (cylinder head temperature) of the cylinder head portion. It is effective for increasing the cylinder block temperature in the warm-up operation that the cylinder-block flow rate is set lower than the cylinder-head flow rate.

Therefore, in the warm-up operation, the coolant may be distributed to the low-flow-rate heat exchanger from the cylinder block passage in which a coolant flow rate is relatively low, and the coolant may be distributed to the high-flow-rate heat exchanger from the cylinder head passage in which a coolant flow rate is relatively high. As a result, the coolant can be distributed to the first and second heat exchangers at the desired flow rates, and the warm-up of the engine can be accelerated.

The second heat exchanger may include an EGR cooler that cools EGR gas through heat exchange with the coolant flowing therethrough, and the EGR gas is a part of exhaust gas flowing back to an intake side of the engine. The coolant circulation system may further include a first bypass passage through which the coolant bypasses the radiator, and a thermostat that controls the coolant to flow through the first bypass passage when a coolant temperature is equal to or lower than a preset temperature of the thermostat. The preset temperature of the thermostat may be set higher than a temperature below which moisture contained in the EGR gas condenses, and lower than a target coolant temperature in the cylinder block portion. The target coolant temperature in the cylinder block portion may be a temperature at which friction loss between the cylinder block portion and the pistons is lower than a predetermined value.

When the warm-up operation is finished, the cylinder block temperature is different from the cylinder head temperature in optimum value. When the cylinder head temperature is too low, the moisture contained in the EGR gas may be cooled excessively to condense, and the condensed moisture may erode a metallic component, for example. When the cylinder head temperature is too high, knocking may occur in a case where a driver presses a gas pedal to accelerate a vehicle. Based on these, the optimum value of the cylinder head temperature may be determined. On the other hand, the optimum value of the cylinder block temperature may be determined so that the fiction loss becomes equal to or lower than the predetermined value.

Hence, it is effective for preventing the knocking that the cylinder head temperature is set lower than the optimum value (e.g., 90° C.) of the cylinder block temperature after the warm-up operation is finished. Moreover, the cylinder head temperature may be higher than the condensation temperature below which the moisture contained in the EGR gas condenses.

In general, the preset temperature of the thermostat may be set based on the friction loss. In this case, the cylinder head temperature can be increased easily to be higher than a temperature (head inflow temperature) controlled by the thermostat. However, the cylinder head temperature may be difficult to be reduced to be lower than the head inflow temperature.

Therefore, the preset temperature of the thermostat may be set lower than the target coolant temperature in the cylinder block portion (i.e., the optimum value of the cylinder block temperature), and higher than the condensation temperature of the moisture contained in the EGR gas. Accordingly, the cylinder head temperature can be set at the optimum value thereof easily.

In this case, the temperature (head inflow temperature) controlled by the thermostat may often be lower than the optimum value of the cylinder block temperature, and the cylinder block temperature can be increased easily by reducing the cylinder-block flow rate. Accordingly, the cylinder block temperature also can be set at the optimum temperature (target coolant temperature) thereof easily.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure, together with additional objectives, features and advantages thereof, will be best understood from the following description, the appended claims and the accompanying drawings, in which:

FIG. **1** is a schematic diagram showing a coolant circulation system for an engine, according to an exemplar embodiment of the present disclosure;

FIG. **2** is a time chart showing changes of various temperatures and flow rates in the coolant circulation system according to the exemplar embodiment; and

FIG. **3** is a schematic diagram showing a coolant circulation system for an engine, according to a modification of the present disclosure.

DETAILED DESCRIPTION

An exemplar embodiment of the present disclosure will be described hereinafter referring to drawings.

In a coolant circulation system of an exemplar embodiment shown in FIG. **1**, a coolant discharged from a pump **10** passes through water jackets provided respectively in a cylinder block portion **21** and a cylinder head portion **22** of an engine **20**. The water jacket provided in the cylinder block portion **21** is a cylinder block passage **21***a*, and the water jacket provided in the cylinder head portion **22** is a cylinder head passage **22***a*. The cylinder block passage **21***a* and the cylinder head passage **22***a* are connected in parallel to each other as shown in FIG. **1**. The cylinder block portion **21** accommodates therein pistons, and the cylinder head portion **22** defines a combustion chamber of the engine **20**.

The coolant flowing out of the cylinder block passage **21***a* and the cylinder head passage **22***a* flows into a radiator **40** through a control valve unit **30** to exchange heat with outside air in the radiator **40**. Subsequently, the coolant returns to the pump **10**. Thus, the coolant circulates in an order: the pump **10**→the cylinder block portion **21** and the cylinder head portion **22**→the control valve unit **30**→the radiator **40**→the pump **10**. The control valve unit **30** is used as an example of a control unit configured to be capable of controlling a flow rate of the coolant flowing through the cylinder block passage **21***a* and a flow rate of the coolant flowing through the cylinder head passage **22***a* respectively.

A thermostat **41** is provided downstream of the radiator **40** in a flow of the coolant, and is opened when a coolant temperature is larger than a preset temperature (e.g., 90° C.). Hence, when the engine **20** is warmed up in a warm-up operation, the thermostat **41** is closed so that the coolant circulates through a bypass passage **42** (first bypass passage) that bypasses the radiator **40**. Accordingly, warming of the coolant temperature is accelerated, and temperature warming of the cylinder block portion **21** and the cylinder head portion **22** are thereby accelerated. As a result, the engine **20** can be warmed up quickly.

The engine **20** shown in FIG. **1** includes an exhaust gas circulation system (EGR system) in which a part of exhaust gas adapted as EGR gas flows back to an intake side of the engine **20**. The EGR system includes an EGR cooler **51** that cools the EGR gas via heat exchange with the coolant, and an EGR valve **52** that controls a flow rate of the EGR gas. The EGR valve **52** has a cooling jacket **53** through which the coolant passes, and the EGR valve **52** is cooled via heat exchange with the coolant passing through the cooling jacket **53**.

A throttle valve **54** that adjusts a flow rate of intake air has a cooling jacket **55** through which the coolant flows. The throttle valve **54** is cooled via heat exchange with the coolant passing through the cooling jacket **55**. The coolant circulating due to pumping of the pump **10** is used also as a heat exchange medium in a heater core **56** (heat exchanger) and an oil warmer **57** (heat exchanger). The heater core **56** heats conditioned air blown into a vehicle compartment via heat exchange with the coolant. The oil warmer **57** heats lubricant oil used for sliding surfaces, for example, between cylinder liners and the pistons of the engine **20**, or heats lubricant oil used for a transmission device via heat exchange with the coolant.

The control valve unit **30** includes control valves **31**, **32** that control a flow rate (cylinder-block flow rate Vs) in the cylinder block passage **21***a*, and control valves **33**, **34** that control a flow rate (cylinder-head flow rate Vh) in the cylinder head passage **22***a*. Opening and closing operations of these control valves **31** to **34** are actuated by an electric control unit **60** (ECU).

A coolant temperature (cylinder block temperature Ts) flowing at an outlet of the cylinder block passage **21** a is detected by a cylinder-block temperature sensor **21***b*, and a coolant temperature (cylinder head temperature Th) flowing at an outlet of the cylinder head passage **22***a* is detected by a cylinder-head temperature sensor **22***b*. The ECU **60** controls the control valves **31** to **34** based on the cylinder block temperature and the cylinder head temperature detected by the temperature sensors **21***b* and **22***b*.

The coolant flowing out of the cylinder block passage **21***a* is distributed to the oil warmer **57** through a distribution passage s**1** (first distribution passage) and to the radiator **40** through a radiator passage s**2** (first radiator passage). The control valve **31** controls a flow rate Vs**1** in the distribution passage s**1**, and the control valve **32** controls a flow rate Vs**2** in the radiator passage s**2**. Hence, when open degrees of both of the control valves **31** and **32** are reduced, the cylinder-block flow rate Vs can be reduced. In other words, the cylinder-block flow rate Vs can be adjusted by the controls of the control valves **31**, **32**. The oil warmer **57** is used as an example of a first heat exchanger connected to an outlet of the cylinder block passage **21***a* via the distribution passage s**1**.

The coolant flowing out of the cylinder head passage **22***a* is distributed to the heater core **56** and the EGR cooler **51** through a distribution passage h**1** (second distribution passage), to the radiator **40** through a radiator passage h**2** (second radiator passage), and to the cooling jackets **53**, **55** through a distribution passage h**3**. The control valve **33** controls a flow rate Vh**1** in the distribution passage h**1**, and the control valve **34** controls a flow rate Vh**2** in the radiator passage h**2**. The heater core **56** and the EGR cooler **51** are used as examples of a second heat exchanger connected to an outlet of the cylinder head passage **22***a* via the distribution passage h**1**. The radiator **40** is connected to both the outlet of the cylinder block passage **21***a* via the radiator passage s**2** and the outlet of the cylinder head passage **22***a* via the radiator passage h**2**. The control valve **31** is used as an example of a first control valve provided in the distribution passage s**1** to control a flow rate of the coolant flowing therethrough, and the control valve **33** is used as an example of a second control valve provided in the distribution passage h**1** to control a flow rate of the coolant flowing therethrough. The control valve **32** is used as an example of a third control valve provided in the radiator passage s**2** to control a flow rate of the coolant flowing therethrough, and the control valve **34** is used as an example of a fourth control valve provided in the distribution passage h**2** to control a flow rate of the coolant flowing therethrough.

The distribution passage h**3** is always in communication with the cylinder head passage **22***a* so that a part of the coolant flowing out of the cylinder head passage **22***a* continuously flows into the cooling jackets **53** and **55**. A desired flow rate Vh**3** of the coolant for heat exchange in the cooling jackets **53** and **55** is lower than desired flow rates for heat exchanges in the heat exchangers **51**, **56**, **57**. A pipe diameter of the distribution passage h**3** is set such that the coolant passes therethrough at the desired flow rate Vh**3**. Hence, when open degrees of both the control valves **33** and **34** are reduced, the cylinder-head flow rate Vh can be reduced. In other words, the cylinder-head flow rate Vh can be adjusted by the controls of the control valves **33**, **34**.

Flow rates desired for heat exchanges in the EGR cooler **51**, the heater core **56**, the oil warmer **57**, the cooling jacket **53** and the cooling jacket **55** are set respectively at 10 L/min (EGR-cooler flow rate), 6 L/min (heater-core flow rate), 3 L/min, 1 L/min and 1 L/min, for example. In other words, the desired flow rate of the coolant reduces in the following order: the EGR cooler **51**, the heater core **56**, the oil warmer **57**, the cooling jacket **53** and the cooling jacket **55**.

In the EGR cooler **51** and the heater core **56**, the desired flow rates of the coolant are higher than a predetermined value (e.g., 5 L/min), and the EGR cooler **51** and the heater core **56** may thereby correspond to a high-flow-rate heat exchanger. The EGR cooler **51** and the heater core **56** are connected in series with each other in the distribution passage h**1** to be supplied the coolant from the cylinder head passage **22***a*. In the oil warmer **57**, the desired flow rate of the coolant is lower than the predetermined value, and the oil warmer **57** may thereby correspond to a low-flow-rate heat exchanger. The oil warmer **57** is connected to the distribution passage s**1** to be supplied the coolant from the cylinder block passage **21***a*.

In the cooling jackets **53**, **55**, the desired flow rate of the coolant is lower than that in the low-flow-rate heat exchanger and cannot be adjusted. Thus, the cooling jackets **53** and **55** may correspond to an extremely-low-flow-rate heat exchanger (third heat exchanger), and are connected in series in the distribution passage h**3** to be supplied the coolant from the cylinder head passage **22***a*. The cooling jackets **53** and **55** bypass the heater core **56** through the distribution passage h**3**, and are connected to the EGR cooler **51** in series. Here, the required flow rate in the EGR cooler **51** is larger than the sum of the required flow rates of the cooling jackets **53**, **55** and the heater core **56**. The distribution passage h**3** is used as an example of a second bypass passage that is connected to the outlet of the cylinder head passage **22***a* and bypasses the heater core **56**.

When the coolant flows through the EGR cooler **51** at a temperature lower than a condensation temperature (e.g., 60° C.) of moisture contained in the EGR gas, the EGR gas may be cooled excessively by the EGR cooler **51** so that the moisture contained in the EGR gas may be condensed. The condensed moisture may erode metallic components such as an EGR pipe and the EGR valve **52**. However, when the coolant flows through the EGR cooler **51** at a temperature equal to or more than the condensation temperature, the coolant temperature may set as low as possible above the condensation temperature so that a cooling capacity of the EGR cooler **51** is improved. Therefore, the temperature of the coolant distributed to the EGR cooler **51** may be set at a temperature (e.g., 70° C.) higher sufficiently than the condensation temperature by 10 degrees for example.

A temperature of the coolant distributed to the heater core **56** may be set at a reference temperature, for example, 40° C. When the coolant flows through the heater core **56** below the reference temperature, conditioned air blown into the vehicle compartment may be heated insufficiently in the heater core **56**. Therefore, the control valve unit **30** adjusts a flow rate of the coolant flowing through the heater core at the heater-core flow rate when a temperature of the coolant is higher than the reference temperature. The control valve **30** adjusts the flow rate of the coolant flowing through the heater core at a flow rate lower than the heater-core flow rate when the temperature of the coolant is equal to or lower than the reference temperature.

A largest flow rate of the coolant distributed from the cylinder head passage **22***a* to the high-flow-rate heat exchanger (**51**, **56**) may be set at the desired flow rate (e.g., 10 L/min) in the EGR cooler **51**. A lowest temperature of the coolant distributed from the cylinder head passage **22***a* to the high-flow-rate heat exchanger (**51**, **56**) may be set at a lowest coolant temperature (e.g., 70° C.) in the EGR cooler **51**. The desired flow rate of the coolant in the low-flow-rate heat exchanger (**57**), which is distributed from the cylinder block passage **21***a*, is set at 3 L/min for example as described above. Hence, the desired flow rate in the low-flow-rate heat exchanger (**57**) is lower than the desired flow rate in the high-flow-rate heat exchanger (**51**,**56**).

A temperature of the coolant distributed to the oil warmer **57** may be higher than a temperature of oil that is an object to be heat-exchanged in the oil warmer **57**. An upper limit temperature of the coolant distributed to the oil warmer **57** is higher than that of the coolant distributed to the EGR cooler **51**.

Next, a control of the control valve unit **30** in the warm-up operation will be described with reference to FIG. **2**. FIG. **2** is a time chart showing changes of various temperatures and flow rates when the warm-up operation of the engine **20** is started at 0° C. of the coolant temperature.

An optimum value of the cylinder block temperature Ts may be 90° C. for example. Thus, the open degrees of the control valves **31**, **32** are controlled so that the cylinder-block flow rate Vs becomes as low as possible until a detection value of the cylinder-block temperature sensor **21***b* reaches the optimum value. Accordingly, elevation of the cylinder block temperature can be promoted.

As shown In FIG. **2**, the control valve **31** is fully closed, in other words, the flow rate Vs**1** in the distribution passage s**1** is set at 0 L/min, and the control valve **32** is slightly open, in other words, the flow rate Vs**2** in the radiator passage s**2** is set at 1 L/min from the start until time t**1** at which the cylinder block temperature Ts reaches a lower limit temperature (e.g., 20° C.) of the oil warmer **57**. After time t**1**, the control valve **31** is fully open, in other words, the flow rate Vs**1** is set at 3 L/min, and the control valve **32** is fully closed, in other words, the flow rate Vs**2** is set at 0 L/min, so that the coolant is distributed to the oil warmer **57** at the required flow rate of the oil warmer **57**. Subsequently, the cylinder block temperature Ts reaches the optimum value (e.g., 90° C.) thereof at time t**3**. After time t**3**, the open degree of the control valve **32** is adjusted so that the cylinder block temperature Ts is kept at the optimum value thereof.

An optimum value of the cylinder head temperature Th may be 70° C., for example. The open degrees of the control valves **33**, **34** are controlled so that the cylinder-head flow rate Vh becomes as low as possible until a detection value of the cylinder-head temperature sensor **22***b* reaches the optimum value. Accordingly, elevation of the cylinder head temperature Th can be promoted.

As shown in FIG. **2**, the control valve **33** is fully closed, in other words, the flow rate Vh**1** in the distribution passage h**1** is set at 0 L/min, and the control valve **34** is also fully closed, in other words, the flow rate Vh**2** in the radiator passage h**2** is set at 0 L/min from the start until time t**2** at which the cylinder head temperature Th reaches the reference temperature (e.g., 40° C.), i.e., a lower limit temperature of the heater core **56**. Thus, the cylinder-head flow rate Vh is equal to the flow rate Vh**3** of the coolant flowing through the cooling jackets **53** and **55**, in other words, the cylinder-head flow rate Vh is set at 1 L/min. After time t**2**, the control valve **33** is open, in other words, the flow rate Vh**1** is set at 6 L/min, and the control valve **34** is fully closed, in other words, the flow rate Vh**2** is set at 0 L/min, so that the coolant is distributed to the heater core **56** at the required flow rate of the heater core **56**.

Subsequently, the open degree of the control valve **33** is enlarged at time t**4**, at which the cylinder head temperature Th reaches a lower limit temperature (e.g., 70° C.) of the EGR cooler **51**, so that the coolant is distributed to the EGR cooler **51** at the required flow rate of the EGR cooler **51**. For example, in FIG. **2**, the control valve **33** is fully opened, and the control valve **34** is fully closed at time t**4**. After time t**4**, the open degree of the control valve **34** is adjusted so that the cylinder head temperature Th becomes the optimum value thereof.

If the control valves **33**, **34** are omitted, the cylinder-head flow rate Vh cannot be controlled. Thus, as shown by a dashed-dotted L**1** in FIG. **2**, the cylinder-head flow rate Vh is set always at a largest value, and cannot be reduced. As a result, the cylinder head temperature Th may increase slowly as shown by a dashed-dotted L**3** in FIG. **2**, and the warm-up operation cannot be thereby promoted.

If the coolant is distributed from the cylinder block passage **21***a* to the heater core **56**, the control valve **31** is required to be opened when the cylinder block temperature Ts reaches the reference temperature (e.g., 40° C. in FIG. **2**). Therefore, as shown by a dashed-dotted L**2** in FIG. **2**, the cylinder-block flow rate Vs increases in the warm-up operation. As a result, the cylinder block temperature Ts may increase slowly as shown by a dashed-dotted L**4** in FIG. **2**, and the warm-up operation cannot be thereby promoted.

In the above-described embodiment, the cylinder-head flow rate Vh and the cylinder-block flow rate Vs can be controlled respectively by using the control valve unit **30** though the pump **10** is mechanically operated by drive force generated by the engine **20**.

The cylinder-head flow rate Vh necessary for keeping the cylinder head temperature Th at the optimum value thereof is higher than the cylinder-block flow rate Vs necessary for keeping the cylinder block temperature Ts at the optimum value thereof. Additionally, the optimum value of the cylinder head temperature Th is lower than the optimum value of the cylinder block temperature Ts. Based on these, the coolant flowing out of the cylinder head passage **22***a* is distributed to the EGR cooler **51** and the heater core **56** because the coolant flowing through the ERG cooler **51** and the heater core **56** is required to have a low temperature and a high flow rate as compared to the coolant flowing through the oil warmer **57**. As a result, the coolant can be distributed to the EGR cooler **51** and the heater core **56** at the required flow rate while the elevations of the cylinder block temperature Ts and the cylinder head temperature Th can be promoted. In other words, the warm-up operation can be promoted while the coolant can be distributed to the EGR cooler **51** and the heater core **56** at the required flow rate.

In the exemplar embodiment, the preset temperature of the thermostat **41** is set at the optimum value of the cylinder block temperature Ts that is a target coolant temperature in the cylinder block portion **21**. Alternatively, the preset temperature of the thermostat **41** may be set lower than the target coolant temperature in the cylinder block portion **21**, and higher than the condensation temperature below which the moisture contained in the EGR gas condenses.

The target coolant temperature (e.g., 90° C.) of the cylinder block portion **21** is a temperature at which friction loss between the cylinder block portion **21** and the pistons accommodated in the cylinder block portion **21** is smallest. When the cylinder block temperature Ts decreases, viscosity of the lubricant oil increases, and the friction loss between the cylinder block portion **21** and the pistons may thereby increase. When the cylinder block temperature Ts increases, the pistons expand due to heat, and the friction loss between the cylinder block portion **21** and the pistons may thereby increase. Therefore, the target coolant temperature in the cylinder block portion **21** is set at the temperature at which the friction loss is smallest, in consideration of the balance between the viscosity of the lubricant oil and the heat expansion of the pistons.

The optimum value (e.g., 70° C.) of the cylinder head temperature Th, i.e., a target coolant temperature in the cylinder head portion **22** is lower than the optimum value of the cylinder block temperature Ts. Because the cylinder head temperature Th has little influence on a temperature of the lubricant oil as compared with the cylinder block temperature Ts, the optimum value of the cylinder head temperature Th may be set lower than the optimum value of the cylinder block temperature Ts. The cylinder head temperature Th has great influence on a temperature of the combustion chamber in the engine **20**. Hence, when the cylinder head temperature Th is higher than the optimum value thereof (e.g., 70° C.), knocking may be generated in the combustion chamber of the engine **20** in a case where a driver presses on a gas pedal to accelerate a vehicle.

When the cylinder head temperature Th is reduced too much, the EGR gas may be cooled excessively through heat exchange with the coolant distributed to the EGR cooler **51**. As a result, the moisture contained in the EGR gas may be condensed. Hence, the target coolant temperature in the cylinder head portion **22** is set higher than the condensation temperature of the moisture, and lower than the target coolant temperature in the cylinder block portion **21**.

Here, if the preset temperature of the thermostat **41** is set at the target coolant temperature in the cylinder block portion **21**, a temperature of the coolant may be higher than the target coolant temperature in the cylinder head portion **22** after the warm-up operation. Consequently, the cylinder head temperature Th may be difficult to be reduced to be the optimum value thereof after the warm-up operation. When the preset temperature of the thermostat **41** is set at the target coolant temperature in the cylinder head portion **22**, in other words, when the preset temperature of the thermostat **41** is set lower than the target coolant temperature in the cylinder block portion **21** and higher than the condensation temperature of the EGR gas, the cylinder head temperature Th can be adjusted at the optimum temperature thereof easily. The cylinder block temperature Ts can be increased to be the optimum temperature thereof by reducing the cylinder-block flow rate Vs.

Although the present disclosure has been fully described in connection with the exemplar embodiment thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications described below will become apparent to those skilled in the art.

In the above-described exemplar embodiment, the pump **10** is mechanically operated by drive force of the engine **20**. Alternatively, a pump electrically operated by drive force generated by an electric motor **11** may be used as the pump **10**, as shown in FIG. **3**. In this case, the electric motor **11** may be controlled by the ECU **60**, and the control valve **33** may be omitted as shown in FIG. **3**. Even when the control valve **33** is omitted in this case, the control valve unit **30** is capable of controlling the cylinder-block flow rate Vs and the cylinder-head flow rate Vh respectively. Furthermore, a discharge capacity of the pump **10** can be controlled so as to keep the flow rates Vh**2**, Vs**2** of the coolant flowing to the radiator **40** at zero until the coolant temperature reaches the preset temperature of the thermostat **41**. Thus, the bypass passage **42** can be omitted. As a result, when the electric pump is adopted as the pump **10**, the number of control valves of the control valve unit **30** can be reduced, and the bypass passage **42** can be omitted.

In the above-described exemplar embodiment, two-way valves are adopted as the control valves **31** to **34** of the control valve unit **30**, which control a communication state between two passages. Alternatively, three-way valve may be adopted as the control valves of the control valve unit **30**, which control a communication state among three passages. In this case, the number of the control valves of the control valve unit **30** can be reduced. For example, the control valve unit **30** may include a three-way valve that controls a communication state among the cylinder head passage **22***a*, the distribution passage h**1** and the radiator passage h**2**, and a three-way valve that controls a communication state among the cylinder block passage **21***a*, the distribution passage s**1** and the radiator passage s**2**. These three-way valves switch the communication states and adjust a flow rate of each of the passages.

Additional advantages and modifications will readily occur to those skilled in the art. The disclosure in its broader terms is therefore not limited to the specific details, representative apparatus, and illustrative examples shown and described.

What is claimed is:

1. A coolant circulation system for an engine that includes a cylinder block portion and a cylinder head portion, the coolant circulation system comprising:

- a cylinder block passage provided in the cylinder block portion to serve as a passage through which a coolant flows to cool the cylinder block portion,
- a cylinder head passage provided in the cylinder head portion to serve as a passage through which the coolant flows to cool the cylinder head portion, wherein the cylinder block passage and the cylinder head passage are connected in parallel to each other;
- a first heat exchanger connected to an outlet of the cylinder block passage without being connected to an outlet of the cylinder head passage;
- a second heat exchanger connected to the outlet of the cylinder head passage without being connected to the outlet of the cylinder block passage;

a radiator connected to both the outlet of the cylinder block passage and the outlet of the cylinder head passage, such that coolant from the outlet of the cylinder block passage and the outlet of the cylinder head passage flows through the radiator before returning to the cylinder block passage or the cylinder head passage;

a control valve unit including a first control valve that controls a flow rate of the coolant flowing through the cylinder block passage, and a second control valve that controls a flow rate of the coolant flowing through the cylinder head passage, the control valve unit being capable of controlling the flow rate of the coolant flowing through the cylinder block passage and the flow rate of the coolant flowing through the cylinder head passage respectively,

wherein the radiator is configured to be connected to both the outlet of the cylinder block passage and the outlet of the cylinder head passage when the first heat exchanger is connected to the outlet of the cylinder block passage without being connected to the outlet of the cylinder head passage and when the second heat exchanger is connected to the outlet of the cylinder head passage without being connected to the outlet of the cylinder block passage.

2. The coolant circulation system according to claim **1**, wherein

the first heat exchanger is a heat exchanger in which a desired flow rate of the coolant for heat exchange therein is lower than a predetermined value, and

the second heat exchanger is a heat exchanger in which a desired flow rate of the coolant for heat exchange therein is higher than the predetermined value.

3. The coolant circulation system according to claim **1**, wherein

the second heat exchanger includes an EGR cooler that cools EGR gas through heat exchange with the coolant flowing therethrough, and

the EGR gas is a part of exhaust gas flowing back to an intake side of the engine.

4. The coolant circulation system according to claim **3**, further comprising:

a first bypass passage through which the coolant bypasses the radiator; and

a thermostat that controls the coolant to flow through the first bypass passage when a temperature of the coolant is equal to or lower than a preset temperature of the thermostat, wherein

the preset temperature of the thermostat is set higher than a temperature below which moisture contained in the EGR gas condenses, and lower than a target coolant temperature in the cylinder block portion, and

the target coolant temperature in the cylinder block portion is a temperature at which a friction loss between the cylinder block portion and the pistons is lower than a predetermined value.

5. The coolant circulation system according to claim **2**, wherein the first heat exchanger includes an oil warmer that heats lubricant oil used for the engine.

6. The coolant circulation system according to claim **2**, wherein the second heat exchanger includes a heater core that exchanges heat with conditioned air,

the coolant circulation system further comprising:

a second bypass passage connected to the outlet of the cylinder head passage without being connected to the outlet of the cylinder block passage, the second bypass passage bypassing the heater core, and

a third heat exchanger provided in the second bypass passage, the third heat exchanger being a heat exchanger in which a desired flow rate of the coolant for heat exchange therein is lower than that in the first heat exchanger.

7. The coolant circulation system according to claim **6**, wherein

the control valve unit adjusts a flow rate of the coolant flowing through the heater core at a heater-core flow rate when a temperature of the coolant is higher than a reference temperature below which the conditioned air is heated insufficiently, and

the control valve unit adjusts the flow rate of the coolant flowing though the heater core at a flow rate lower than the heater-core flow rate when the temperature of the coolant is equal to or lower than the reference temperature.

8. The coolant circulation system according to claim **1**, wherein the control valve unit includes at least one valve provided downstream of the cylinder block passage in a coolant flow, and at least one valve provided downstream of the cylinder head passage in a coolant flow.

9. The coolant circulation system according to claim **8**, wherein

the first heat exchanger is connected to the outlet of the cylinder block passage via a first distribution passage,

the second heat exchanger is connected to the outlet of the cylinder head passage via a second distribution passage, and

the first control valve is provided in the first distribution passage, and the second control valve provided in the second distribution passage.

10. The coolant circulation system according to claim **8**, wherein

the radiator is connected to the outlet of the cylinder block passage via a first radiator passage and the outlet of the cylinder head passage via a second radiator passage, and

the control valve unit includes a third control valve provided in the first radiator passage to control a flow rate of the coolant flowing therethrough, and a fourth control valve provided in the second radiator passage to control a flow rate of the coolant flowing therethrough.

11. The coolant circulation system according to claim **1**, further comprising a pump connected to the engine to supply the coolant to the engine.

12. The coolant circulation system according to claim **11**, wherein the pump is electrically operated by a drive force generated by an electric motor.

13. The coolant circulation system according to claim **1**, wherein the cylindrical portion accommodates therein pistons, and the cylinder head portion defines a combustion chamber.

14. The coolant circulation system according to claim **6**, wherein the third heat exchanger includes a cooling jacket that cools an EGR valve.

15. The coolant circulation system according to claim **6**, wherein the third heat exchanger includes a cooling jacket that cools a throttle valve which adjusts a flow rate of intake air.

16. The coolant circulation system according to claim **6**, wherein the second bypass passage is connected to the cylinder head passage without going through the control valve.

17. The coolant circulation system according to claim 9, wherein

the radiator is connected to the outlet of the cylinder block passage via a first radiator passage branched from the first distribution passage,

the radiator is connected to the outlet of the cylinder head passage via a second radiator passage branched from the second distribution passage, and

the control valve unit includes a third control valve provided in the first radiator passage to control a flow rate of the coolant flowing therethrough, and a fourth control valve provided in the second radiator passage to control a flow rate of the coolant flowing therethrough.

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